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Determinants of success for promoting solar energy in Rajasthan, India

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ABSTRACT

Out of a total 1100 MW new project allocations, Rajasthan received the maximum share of 873 MW (i.e., 79.36% of all India allocations) through competitive bidding in the first phase of Jawaharlal Nehru National Solar Mission (JNNSM). Furthermore, 722 reputed companies have already registered their interest for setting up of solar power plants amounting to a total capacity of 16,900 MW in Rajasthan. This preference is often attributed to geographical and climatic advantage of Rajasthan. Yet it remains unclear why some other States with similar climatic and geographical factors are less favored by investors? Here we argue that the answer to this paradox lies in other determinants such as policy, infrastructure, facilitation and governance that make Rajasthan a lucrative investment opportunity. The fact that our argument is robust is also validated by other studies that indentify critical barriers which if removed may provide enabling environment to solar energy development in India. Accordingly, we present a practitioner perspective and review the initiatives responsible for accelerated development of solar energy in Rajasthan. We also envision the future course of actions for this promising solar hotspot in western India. Understanding early ground-level efforts for solar energy development in Thar desert of Rajasthan may prove valuable for other regions in India and elsewhere.

Contents

1. Introduction

Solar energy is the largest exploitable renewable resource as more energy from sunlight strikes Earth in 1 h than all of the energy consumed by humans in an entire year [1]. Solar energy is also appealing because stabilizing the carbon dioxide-induced climate

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change is mainly an energy problem, and thus stabilization will require the development of renewable sources that do not emit carbon dioxide to the atmosphere [2,3]. Solar energy is abundant and offers a solution to fossil fuel emissions and global climate change. Earth receives solar energy at the rate of approximately 1,20,000 TW (1 TW = 10^{12} W or 1 trillion watt). This enormously exceeds both the current annual global energy consumption rate of about 15 TW, and any conceivable requirement in future [4].

Driven by perpetually rising demand for energy, more than 100 countries including India have enacted policies and programs for harnessing solar energy. The achievements, however, have been mixed so far. This review provides the practitioner perspective and reviews the progress made in development of solar energy in Thar desert, Rajasthan—among the most promising solar hotspots in India. We not only review the success but also critically evaluate the areas of concern. While envisioning the future, we identify several critical areas that have implication for practice and research, including the data gaps where serious attention would need to be given by practitioners and researchers. Understanding early ground-level efforts for solar energy development is essential, as these insights can prove vital for other regions in India and elsewhere.

Rajasthan, the largest state of India constitutes about 10.4% geographical area of India. Notwithstanding the recently discovered large hydrocarbon reserves of more than 3.6×10^9 barrel oil and oil equivalent in Barmer basin [5], there are limited available traditional sources of energy such as coal. There are only two perennial rivers, Chambal and Mahi, whose hydroelectric potential has been almost fully achieved. In view of the above, Rajasthan faces two unique challenges in terms of power generation from the conventional sources: one, there are not many hydropower projects due to non-availability of large rivers; two, as coal needs to be transported from other states, the transportation alone contributes to 50% cost of energy production. Rajasthan has about 2,08,110 km^2 of desert land, which is 60% of the total area of the state. Interestingly, Rajasthan receives solar radiation of 6.0–7.0 kWh/m^2. As the area has low rainfall, about 325 days have good sunshine in a year [6], and in western areas in Thar desert it may extend up to 345–355 days as rains occur only for 10.4–20.5 days in a year [7].

2. Potential of solar energy in India

The average intensity of solar radiation received over India is 200 MW/km^2 (megawatt per kilometer square) with 250–325 sunny days in a year. Solar energy intensity varies geographically in India, but the highest annual global radiation ($\geq$2400 kWh/m^2) is received in Rajasthan and northern Gujarat [8]. India receives the solar energy equivalent of more than 5000 trillion kWh/year. Depending on the location, the daily incidence ranges from 4 to 7 kWh/m^2, with the hours of sunshine ranging from 2300 to 3200 per year [9,10]. Recent research has shown that India has a vast potential for solar power generation since about 58% of the total land area (1.89 million km^2) receives annual average Global insolation above 5 kWh/m^2/day. Indeed, at present efficiency levels, 1% of land area is sufficient to meet electricity needs of India till 2031 [11,12]. The cost remains a challenge as each megawatt of solar power installation costs around INR 11 crores (i.e., INR 110 million), while that of wind power is INR 5 crores (i.e., INR 50 million).

3. Current policy, practice and regulations in India

In terms of all renewable energy, currently India is ranked fifth in the world with 15,691.4 MW grid-connected and 367.9 MW off-grid renewable energy based power capacity [11]. Development of alternate energy is administered through India's Ministry of New Renewable Energy (MNRE), National Thermal Power Corporation Vidyut Vyapar Nigam Ltd., (NVVNL) Energy development agencies in the various States and the Indian Renewable Energy Development Agency Limited (IREDA). In terms of solar, the amount of solar energy produced in India is less than 1% of the total energy produced. It is almost entirely based on PV technology, and about 20% of the capacity is being used for off-grid applications.

Promoting renewable energy has assumed great importance in view of high growth rate of energy consumption, high share of coal in domestic energy demand, heavy dependence on imports for meeting demands for petroleum fuels and volatility of world oil market [13,14]. Even with a frugal per capita electricity need of 2000 kWh/annum and a scenario of stabilized population of 1700 million by 2070, India would need to generate 3400 TWh/year in future [15]. The Government of India's National Action Plan on Climate Change (NAPCC) released in mid-2008, by the Prime Minister's Council on Climate Change identifies eight critical missions, including Nation Solar Mission, National Mission for Enhanced Energy Efficiency and National Mission for Green India. Among these, the Solar Mission would be implemented in 3 stages, finally deploying 20,000 MW Grid Connected Power Plants, and generating 2000 MW of off-grid solar power covering 20 million m^2 with collectors, by the year 2022 [16]. The NAPCC notes that as much as 15% of India's energy could come from renewable sources by 2020. Accordingly, the NAPCC has presently set a target of 5% of power purchase from renewable sources, which will be increased by 1% each year to reach 15% by 2020.

In addition to the above, the Indian Electricity Act, 2003 also provides for the promotion of co-generation and generation of electricity from renewable sources of energy, and purchase of electricity from such sources. As per the provision of EA, 2003 and National Electricity Policy and Tariff Policy, the Forum of Regulators constituted by the notification dated February 16, 2003 has finalized its recommendations on various issues which includes guidelines for specifying percentage for renewable energy procurement, share of different renewable energy sources within overall renewable procurement obligation (RPO) percentage, competitive procurement of renewable energy, introducing of renewable energy certificate (REC) mechanism [17]. The REC mechanism is aimed at addressing the mismatch between availability of renewable energy resources in state and the requirement of the obligated entities to meet the renewable procurement obligation (RPO) in other states. This has resulted faster overall growth of renewable energy sector in last two years in India. The scenario is likely to get better as India has one of the largest programs in the world for deploying renewable energy based products and systems [18].

4. Determinants of success for renewable energy in Rajasthan

Out of a total 1100 MW new project allocations, Rajasthan received the maximum share of 873 MW (i.e., 79.36% of all India allocations) through competitive bidding in the first phase of Jawaharlal Nehru National Solar Mission (JNNSM). This preference is often attributed to geographical and climatic advantage of Rajasthan. Yet it remains unclear why some other States with similar climatic and geographical factors are less favored by investors? We argue that the answer to this paradox lies in other determinants such as policy, infrastructure, facilitation and governance that make Rajasthan a lucrative investment opportunity.

The fact that our argument originating from practitioner perspective is robust is also validated by other independent studies that indentify critical barriers which if removed may provide enabling environment to solar energy development in India. For instance, a recent World Bank study [19] which examined the

critical barriers for solar power development in India suggests that policy and regulatory aspects were the most significant barriers. In addition, majority of developers rate the infrastructure deficit as a critical barrier. Similar conclusions have been arrived at by many other studies [20,21].

Here, in the sub-sections that follow, we describe the specific initiatives in Rajasthan that are paving the way for accelerated development of solar energy. A word of clarification shall be in order here. While this section reviews the determinants of success, we do not ignore the critical areas of concern that still remain to be addressed in Rajasthan. Accordingly, in the subsequent section on envisioning the future (Section 5), several issues and data gaps that have implication for research and practice have been presented.

4.1. Renewable and solar policy

To promote the renewable energy sector in general and solar energy in particular, Government of Rajasthan has taken several important initiatives. To begin with “Policy for Promoting Generation of Power through Non-Conventional Energy Sources” was enacted on 11 March 1999, which was updated in year 2000, 2003 and 2004 [22]. Also, Government of Rajasthan on 19 April 2011, issued Rajasthan Solar Energy Policy, 2011 to promote Solar Energy. The main objectives of this policy include: leverage maximum benefit from National Solar Mission, develop Solar Power Plants for meeting renewable purchase obligation of Rajasthan as well as other States, promote off-grid applications of solar energy, and the development of solar parks. Other important policy initiatives of Government of Rajasthan embodied in the Climate Change Agenda of Rajasthan, Rajasthan Environment Mission, Rajasthan Environment Policy 2010, and State Action Plan on Climate Change [23], recognize the role of solar energy for sustainable development and energy security. With various policy initiatives including allotment of government land at 10% of District Level committee (DLC) rate, 1766 MW Wind Farms and 106 MW of Biomass Plants are already in operation.

4.2. State nodal agency and single window clearance

Government of Rajasthan established the Rajasthan Renewable Energy Corporation Limited (RRECL) in year 2003 by merging erstwhile Rajasthan Energy Development Agency and the Rajasthan State Power Corporation Limited to act as state nodal agency for single window clearance of the renewable energy projects. This was also to facilitate the allotment of revenue land, power evacuation approval, execution of PPAs and coordination with MNRE and State Agencies including State Transmission Utility (STU) and Discoms. RRECL is also working as a state nodal agency for promoting and developing non-conventional energy sources and as a State Designated Agency (SDA) for enforcement of provisions of Energy Conservation Act 2001. It is also engaged in creating awareness among people toward conservation of energy through demonstration projects.

4.3. Robust power evacuation system in Thar desert

Energy production systems such as wind farms and solar systems are mostly located in desert districts such as Jaisalmer, Jodhpur, Barmer, but load centers are situated away from these districts. Evacuation and transmission of power therefore was required to be strengthened. Accordingly, a dedicated 400 kV network with associated 220 and 132 kV strong transmission network in Barmer, Jaisalmer, Jodhpur, Bikaner area was created. Rajasthan is the only State in India, which has established a strong power evacuation network in a desert region. Existence of suitable transmission system for evacuating solar power in a desert area, a hotspot of solar energy, has been one of the key factors in early wins for Rajasthan compared to other states in India. RVPN is further strengthening the infrastructure with an investment of INR 2900 crores (INR 29,000 million) for 400 kV GSS at Jodhpur and Jaisalmer solar parks for transmission lines associated with Solar Parks.

4.4. Early mover advantage in solar sector

Even before the creation of National Solar Mission, Govt. of Rajasthan has taken an initiative in 2008 and approved 2 Solar Projects each of 5 MW under Generation Based Incentive Scheme (GBI). To provide encouragement in solar sector, Rajasthan Electricity Regulatory Commission (RERC) issued orders on 2 April 2008, first time in India, imposing solar specific renewable procurement obligation (RPO) for Discom in Rajasthan. To meet out RPO requirement, the State Government approved Solar Projects of 11 private sector developers for setting up of 66 MW capacity systems utilizing all available technologies in solar photovoltaic (PV) and concentrating solar power (CSP). After announcement of Jawaharlal Nehru National Solar Mission, Government of Rajasthan permitted these proposals to be migrated to the National Solar Mission. The seven solar power plants, each of 5 MW, having Photovoltaic technology are already commissioned under the migration scheme of National Solar Mission, while the Solar Thermal Plants of 30 MW are under implementation. These early initiatives provided Rajasthan an edge over other states.

RREC has issued the RPOs and regulations for renewable energy from time to time. Feed-in tariff for renewable energy projects have also been decided. The RERC (REC and RPO Compliance Framework) Regulations, 2010 have also been issued on 23 December 2010. Recently, RERC issued revised RPO to make it more realistic to what is being achieved by Distribution Licensees (Discoms). Current RPO component for wind and solar power is 4.5% and 0.5%, respectively.

In the year 2011, Union Ministry of New and Renewable Energy under National Solar Mission selected investors for setting up of solar power plant of 800 MW capacities under the phase I of National Solar Mission. In fact, to offset the higher cost of solar power, the mechanism has been developed to bundle the solar power along with the unallocated portion of the power available with National Thermal Power Corporation. In the competitive bids, the tariff for solar energy came in the range of INR 11 to 12 per unit, whereas the cost of the unallocated conventional energy was about INR 3. Therefore, per unit cost of the bundled energy has been around INR 4.5 per unit.

4.5. Effective environmental governance

The Rajasthan State Pollution Control Board (RSPCB) has made categorization of industries, projects, and processes into Red, Orange and Green category keeping in view the evidence-based gravity of the impact upon the environment. Red category units have the maximum, and Green category have minimum potential for environmental pollution. The new classification into Red, Orange and Green category is to bring coherence with the classification made by the Central Pollution Control Board, New Delhi, with the core aim to improve environmental compliance and enforcement for the larger benefit of people. The categorization has also been done to facilitate designing of the online consent management system for time-bound decision on applications in which project proponents may not be required to visit any office of RSPCB for applying or obtaining consents and authorizations. The powers in respect of grant of consent in solar energy projects have been delegated to the level of Regional Office.

To further accelerate the process of consents and authorizations, the RSPCB has established a fast track approval system (the “tatkal”

mechanism) wherein the decisions are taken within 7 working days of submission of complete applications by project proponents.

Prevailing policies consider solar energy as an almost absolute clean and safe energy source with tremendous environmental benefits [24–27]. However, sunlight is dilute as the yearly averaged solar power striking the Earth's surface is about 170 W/m^2 [28]. Thus, efficiently capturing and storing this energy, in an environmentally friendly manner, continues to be one of the crucial challenges. Accordingly, RSPCB examined the available scientific and experiential knowledge on environmental impacts of installation and commissioning of solar power systems from the perspective of land use change, biodiversity, climate change and wider social—ecological interactions. On majority of indicators the solar power was found to be comparatively environment-friendly, yet there are some areas of concern such as clearing of vegetation in an area dominated by mobile tropical sand dunes that already has sparse vegetation. Consequently RSPCB provides science-based policy options and strategies for environmental enforcement and compliance to promote effective environmental governance [29,30].

In light of these attractive features and the proactive initiatives the State received the first installment of large share of 583 MW, including 3 projects of 100 MW each and 2 projects of 50 MW based on Solar Thermal technologies. The total allocation as on December 2011 amounts to 873 MW (out of 1100 MW in India). In Rajasthan, 41 MW solar photovoltaic power plants and 2.5 MW solar thermal power plants are already operational.

5. Envisioning the future

The potential of Rajasthan for harnessing solar energy and facilitating role of the Government of Rajasthan is now being acknowledged. As discussed here, Rajasthan state is in the advanced stage of preparedness for installation of grid Interactive solar power plants [31]. Encouraged by new initiatives such as single window clearance, solar power producers have registered with Rajasthan Renewable Energy Corporation under renewable energy policy 2004 and now Solar Energy Policy 2011. Thus, 722 reputed companies have already registered their interest for setting up of solar power plants amounting to a total capacity of 16,900 MW in Rajasthan.

In coherence with the Rajasthan Solar policy, state is poised to develop Solar Parks of more than 1000 MW capacity in Jodhpur, Jaisalmer, Bikaner, Barmer and districts in various stages. To begin with, solar park at Jodhpur has already been initiated. Clinton Foundation signed a memorandum of understanding (MoU) with the Government of Rajasthan in January 2010 for setting up 3000 MW Solar Parks. Rajasthan solar Park Private Ltd. (RSP Ltd.), a subsidiary company of RREC will formulate policy and rules for land allotment, selection and qualification of firms, grid connectivity and infrastructure plans, sharing of development cost by the developers and management of solar parks. About 10,000 ha government owned land has already been identified in Jodhpur district. The park has 5000 ha in zone I and 2500 ha in zone II and III each. Survey and soil testing work of 3000 ha of zone I has already been completed. The survey and soil testing of additional 5000 ha of solar park is in process. Consultant appointed by Asian Development Bank has already prepared Master plan of Solar Park.

Rajasthan is also well-positioned to facilitate the RPO of other states through the renewable energy certificate (REC) mechanism if other states so desire. In fact, Rajasthan was the first state to allow open access for wheeling (i.e., power transmission from a seller to a buyer through the network owned by a third party) of solar power to areas beyond Rajasthan. To meet the state specific RPO, Rajasthan is committed to identify and approve more projects through the competitive bidding route. Several collaborations in this direction are already underway [9].

Notwithstanding the initial success, there are several areas of concern that must be addressed in Rajasthan if full potential of solar energy is to be truly realized. Even though the factors favorable for establishment of solar energy harvesting systems are present as discussed here, ensuring the efficiency of installations requires addressing certain key issues that if ignored can obliterate this growth opportunity. For instance, deposition of airborne dust on outdoor PV modules may decrease the transmittance of solar cell glazing and cause a significant degradation of solar conversion efficiency of PV modules. Investors would need to find a cost-effective solution to a common problem of dust deposition to maintain the efficiency of energy production systems as Thar desert experiences frequent dust and sand storms. CSP and PV power plants can lose up to 30% energy output within a few weeks of installation. A dust layer decreases solar power conversion 40% by 4 g m^2 [9]. The effect of soiling and dust deposition on energy production for large-scale photovoltaic plants may considerably deteriorate PVs' performance and compromise the yield of solar parks [32]. These losses can range up to 6.9% for the plants built on sandy soils and a 1.1% for plants built on compact soils [33]. Other studies report that accumulation of 0.4 mg/cm^2 ash on the panel surface can result in 30% energy reduction per hour or 1.5% efficiency decrease [34]. With dust deposition density increasing from 0 to 22 g m^2, the corresponding reduction of PV output efficiency grew from 0% to 26% [35]. It has been suggested that PV systems in Rajasthan may require a minimum weekly cleaning [36], but cleaning thrice a week and washing once a month may be essential in most of the Indian locations [9]. But these suggestions are not based on robust science or long-term field experience. Thus effective approaches would need to be evolved by practitioners, and informed by good science, for appropriate cleaning cycles in Thar desert to mitigate the impact of dust deposition on PV performance. At present this issue is being addressed with trial-and-error approach without any scientific or experiential data. Water use efficiency is another area of concern. There are no studies to determine the water efficiency of solar installations in already water-stressed arid regions such as Rajasthan.

There are other issues that have been overlooked in Rajasthan. As the solar energy development progresses, it would be useful to revisit several other propositions that still remain to be addressed but may have the potential to bring sustainability in the region through solar energy.

- While strong power evacuation system is being strengthened in Rajasthan, the challenge remains because production systems need to be connected and optimally integrated into the grid through the implementation of smart grid technologies. Currently, multiple sources of power production are in operation in Rajasthan. Thus an intelligently optimized auto-balancing and self-monitoring smart power grid capable of accepting power from various sources of fuel including coal, lignite, solar, hydro or wind is necessary [37]. Such grid shall also be necessary to implement the efficient delivery of electricity to large number of distributed consumers [38]. The digitalization of the electricity grid opens the way to bundle value added services to the electricity commodity, and potentially shift business value to electricity services in coherence with the philosophy of efficiency, conservation and sustainability [39]. Urgent efforts would be required in this direction.
- While we have noted the large availability of land and abundant solar radiation in Rajasthan, we want to make it clear that the real issue is not the availability of solar radiation as much as the societal availability of open land. Indeed, contested claims and conflicts over vacant common lands by various stakeholders

including local farmers, cattle herders, villagers, and conservationists are already emerging. Unless there is a fast and reliable conflict resolution and mediation mechanism in place, it will be highly unlikely to sustain the pace of solar energy development in Rajasthan.

- Idea proposed three decades ago to desalinate sea water using solar energy for the Thar Desert of India still remains to be tested in Rajasthan [40]. Solar energy may be utilized to meet the drinking water and other needs of the communities living in remote areas with the help of solar distillation and desalination because it is economical, easy to construct and maintain [41–43]. Likewise, deployment of large number of a solar photovoltaic pump operated drip irrigation system could optimize both energy use and water use efficiency [44].
- Rural India has a tremendous potential to earn carbon credits by setting up household based energy substitution or fuel switching projects like biogas plants, solar cookers and solar cells [45–47]. Yet the issue has not been appropriately addressed in Rajasthan. Indeed, concerted efforts for climate change mitigation and adaptation shall be required [48]. For example, promoting solar water heating systems (SWHs) could be of interest under the Clean Development Mechanism, because they displace greenhouse gas emissions and contribute to sustainable development by reducing local pollutants. Estimates indicate that there is a vast theoretical potential of CO_2 mitigation by the use of solar water heating in India. The annual certified emission reduction (CER) potential of SWHs in India could theoretically reach 27 million tons. Under more realistic assumptions about diffusion of SWHs based on past experiences with the government-run programs, annual CER volumes by 2012 could reach 15–22 million by 2020. Realizing this potential would require concerted efforts [49]. All these assumptions at present remain in paper. Serious efforts would be required to convert the potential into reality.
- Off-grid solar lantern system as small-scale interventions for poorly served rural populations would also need to be aggressively promoted by removing obstacles and encouraging low-cost options to enhance affordability, meaningful participation, improvement in local energy governance, and training local technicians to fill the support gap [50,51]. Implemented properly, solar energy may be far more economical than fossil-fuel based lighting systems such as kerosene lanterns [52].
- Electrification by mini hybrid PV-solar and wind energy system for rural, remote and hilly areas in Rajasthan has been demonstrated to be feasible and could prove to be boon for poor households. These issues are not currently in priority of the State. Large efforts would need to be made to realize the potential [53].
- Exploring the potential of ultra-large scale solar farms may be another area of interest. Studies note that to meet 50% of the total energy demands the proposed area for collection of solar and wind energy by means of ultra-large scale farms in fact will occupy a mere fraction of the available land and near-offshore area, e.g. a solar PV electricity farm of 26 km^2 area required for India represents 0.01% land area of Rajasthan [54].
- Another area where Rajasthan would need to invest is educating the consumers about the benefit of clean energy in the long-term for the society. Without a clear understanding, the society always gives preference to energy sources with low initial financial costs even though these sources have large costs related to climate change adaptation and mitigation in the longer-term [55]. Renewable sources such as solar energy generation systems also create regular jobs locally extending the benefits beyond the income earned from those jobs. Benefits occur when workers spend part of their income in the local economy, generating spin-off benefits known as the 'multiplier effect' [56].
- Currently, solar energy systems in India are almost entirely based on PV technology. Since this solar thermal technology has been successfully implemented in developed countries, with high solar potential, the development of this technology is imperative in Rajasthan [57].
- The vital role of solar power in the energy security of India is accepted, but renewable sources alone may not be sufficient to supply India's electricity needs in the future. A recent analysis clearly indicates that even with a meager per capita electricity need of 2000 kWh/annum and a stabilized population of 1700 million by 2070, India would need to generate 3400 TWh/year. But the total potential of all renewable energy sources in India has been suggested to be only about 1229 TWh/year. Thus, in the future as fossil fuels are exhausted, renewable sources alone will not suffice for meeting India's needs [15]. While these claims require further refinement, energy security shall be an exciting area of multidisciplinary research involving technology, governance and economics to find sustainable solution.
- Finally, we need to watch future trends and take appropriate actions as a number of other factors are likely to decide the future prospects of renewable energy, including global pressure and voluntary targets for greenhouse gas emission reduction, a possible future oil crisis, intensification of rural electrification program, and import of hydropower from neighboring countries [13].

6. Conclusions

For a region that has been more successful in implementing solar energy development, we have highlighted critical success factors and aspects of the enabling environment. The pace of development of solar energy systems has been generally slow globally, because power generation from solar energy is expensive and requires special enabling environment for success. As socio-political and historic framework conditions matter for the implementation of new renewable energy options [58], the pace is now likely to get enhanced because of the Rajasthan Solar Energy Policy 2011, and commitment of the Government of Rajasthan to further develop the crucial infrastructure such as solar parks and power evacuation system. The state is likely to attract an investment of more than Rs. 45,000 crores in the solar energy sector in next two years as it promotes the policy and infrastructure for solar energy.

Overall, as exemplified from initiatives such as state nodal agency and single window clearance, robust power evacuation system, early mover advantage, and effective environmental governance, Rajasthan Government is fully committed to the promotion of solar energy. We believe that implementation of the Rajasthan Solar Energy Policy 2011 as well as addressing the concerns we discussed here will help develop Rajasthan as a global hub of solar power for 10,000–12,000 MW capacity over the next 10–12 years to meet energy requirements of Rajasthan and other states of India. The science over the next decade is likely to develop an efficient photovoltaic material that can be inexpensively produced for use in building exteriors, thereby revolutionizing the use of solar power. Hopefully Rajasthan will be prepared to exploit the opportunity provided the challenges we described here are addressed quickly and appropriately.

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